81 - 7M - 01 - A TWO - BEAMS ACCELERATOR

L. G. Shen C. L. Li Y. G. Liu
Applied Physics Department, National University of Defense Technology
Changsha, Hunan, PRC 410073

ABSTRACT

We report a two - beams accelertor (named 81 - 7M - 01 - A) with one Marx generator operating one 6Ω water Blumlein line and another 40Ω oil Blumlern line at the same time by the use of a magnetic flux coupling isolator to generate two electron beams with different ranges of beam currents. The electron energies and the amplitudes of beam currents may be adjusted respectively in quite large ranges. The functions of this accelerator are equal to that of the operation of two sets of IREBA with different impedances at the same time. In this paper, the operation machanism of the accelerator is outlined, the design method is put forward, and the experiment results are presented. The design parameters are in good agreement with the experiment results. The performances of this accelerator are quite well.

INTRODUCTION

Intense relativistic electron beam accelerator (IREBA) is main equipment for performing such researches as High Power Microwave, Free Electron Lasers, etc. Such equipment may occupy a large space in lab. and may be very expensive. Originally there is a MV IREBA named 81 - 7M - 01 in our Pulsed Power Technology and Plasma Physics Research Lab of National University of Defense Technology. It consists of one Marx generator, one 6Ω water Blumlein line, a vacuum diode etc., and is mainly used for such a type of research as Vircator. On the other hand, we need an IREBA with high impedance output for the purpose of FEL research. In order to save the cost and room occupied by the machine, considering the stored energy in 40Ω oil Blumlein only being about the 1/8 of the stored energy in 81 - 7M - 01 IREBA, we attempt to operate both the 6Ω water Blumlein contained in the 81 - 7M - 01 IREBA originally and the new 40Ω oil Blumlein from the same Marx generator contained in the 81 - 7M - 01 IREBA originally. These two Blumlein lines with different impedances will generate two electron besms at the different ranges of beam currents near the same time. As the first step of this work, we used the method of single inductor isolation to realize the operating two Blumlein generators from one Marx generator. The analysis and experiments on this method had been summerized in literature [1]. To improve the performances of two - beams accelerator operation further, we make use of the magnetic flux coupling isolator, and in the end achieved the reliable operation of two generator. The 81 - 7M - 01 IREBA with single electron beam had been improved into 81 - 7M - 01 - A Two - Beams Accelerator.

THE ANALYSIS AND DESIGN OF 81 - 7M - 01 - A TWO - BEAMS ACCELERATOR

The analysis of operation machanism

In a practical design of such an accelerator with one Marx generator operating two Blumlein lines with different impedances, the following problems should be considered: (I) The transferred energy distribution (or the ratio of charging voltages) between the two Blumlein lines should meet the requirement.

(II) How to introduce the isolation between the oil Blumlein line and the water Blumlein line which will allow them to operate at different time? When one Blumlein switch is fired and after the Blumlein generator begin to operate, the another Blumlein may still con-

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14. ABSTRACT
We report a two - beams accele~or (named 81- 7M -01 -A) with one Marx generator operating one 6Q water Blurnlein line and another 40Q oil Blumlern line at the same time by the use of a magnetic flux coupling isolator to generate two electron beams with different ranges of beam currents. The electron energies and the amplitudes of beam currents may be adjusted respectively in quite large ranges. The functions of this accelerator are equal to that of the operation of two sets of IREBA with different impedances at the same time. In this paper, the operation machanism of the accelerator is outlined, the design method is put forward, and the experiment results are presented. The design parameters are in good agreement with the experiment results. The performances of this accelerator are quite well.

15. SUBJECT TERMS

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tinue to be charged normally, or the influnce on its charging process by the former is as low as allowable.

(Ⅲ) The insertion of the isolator should not increase the charge time too much, or the increase of the charge time should be allowble so that the increase of the energy drain through the water in Blumlein line is low enough, and the decrease of the high voltage insulation strength of the water in Blumlein line is within the original safe margin.

There are two viable options. (Ⅰ) one is the single inductor isolation method. That is, only one inductor with resonable inductance value should be inserted into the charge line between the oil Blumlein line and the Marx generator. The inductance value of the isolation inductor can be derived by numerical simulation leading to a required energy distribution and as higher degree of isolation as possible. The advantages of this method are simple in construction, and easy to insulate. But the raise of the isolation degree is limited. (Ⅱ) The another is the magnetic flux coupling isolation method. The used isolator has two induction coils, Lo and Lw, which are inserted into the charge lines of the oil Bumlein line and water Blumlein line, respectively, and form a mutual inductor by proper connection. This magnetic flux coupling isolator has low inductance during Blumlein charge and high inductance when one Blumlein switch is closed, thus it may have quite good performance. 81 – 7M – 01 – A Two – Beams Accelerator utilizes the magnetic flux coupling isolation method finally.

<u>The calculation of the charge process of the two Blumlein lines</u>

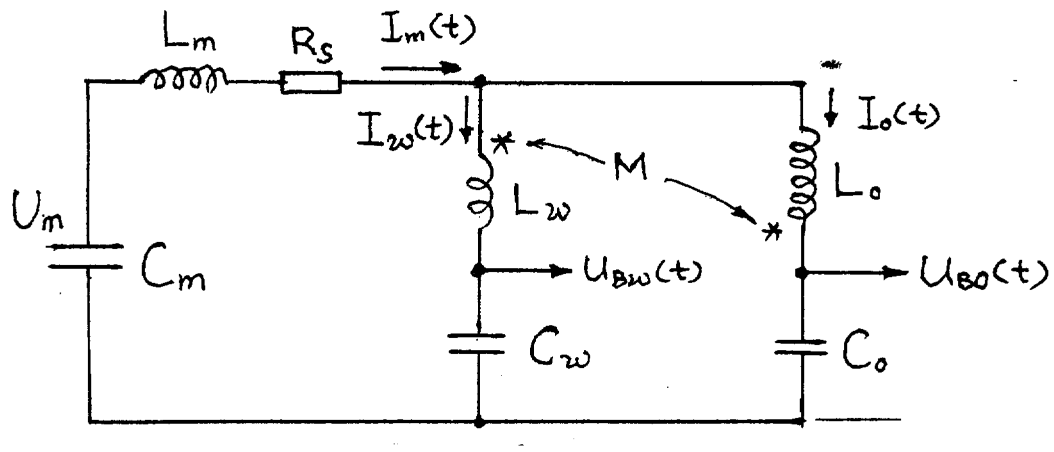

Fig. 1 – The equivalent circuit diagram

The equivalent circuit diagram of the charges of two Blumlein lines from one Marx generator is shown in Fig. 1. From Fig. 1 we can derive the Laplace transformation image functions of the charge currents $I_o(t)$ and $I_w(t)$, $I_o(p)$ and $I_w(p)$ as follows

$$I_0(P) = \frac{\left(1+\frac{M}{L_w}\right)\frac{U_m}{K_4L_0}\left(P^2+\frac{1}{(1+M/L_w)L_wC_w}\right)}{P^4+WP^3+FP^2+GP+H} \tag{1}$$

$$I_w(P) = \frac{\left(1+\frac{M}{L_o}\right)\frac{U_m}{K_4L_w}\left(P^2+\frac{1}{(1+M/L_o)L_oC_o}\right)}{P^4+WP^3+FP^2+GP+H} \tag{2}$$

Where, U_m – the erected voltage of Marx, C_m – the erected capacitance of Marx, L_m – the inner inductance of Marx, R_s – the loss resistance in Marx, C_o – the store capacitance of oil Blumlein, C_w – the store capacitance of water Blumlein; L_o, L_w and M are the inductances and mutual inductance of the isolator, respectively.

We can work out the values of k_4, W, F, G, H from the values of accelerator parameters U_m, C_m, L_m, R_s, C_o, C_w and isolator parameters L_o, L_w and M. Then we can derive the expressions of $I_o(t)$ and $I_w(t)$ from the inversions of Eqs (1) and (2). Finally, according to $U_{BO}(t) = (1/C_o) \cdot \int_0^t I_0(t')dt'$ and $U_{BW}(t) = (1/C_w) \cdot \int_0^t I_w(t')dt'$, we can obtain the expressions of the resonantly charging voltages of the two Blumlein lines from one Marx generator, $U_{BO}(t)$ and $U_{BW}(t)$. They can be expressed as the following expression generally:

$$\overline{U_B(t)} = U_0 \cdot [1 + U_1 e^{-a_1 t} \cdot \cos(b_1 t - \varphi) + U_3 e^{-a_3 t} \cdot \cos(b_3 t - \Psi)] \qquad (3)$$

where, $\overline{U_B(t)} = U_B(t)/U_m$. The difference between $\overline{U_{BO}(t)}$ and $\overline{U_{BW}(t)}$ is that the parameters contained in the coefficients U_o, U_1, a_1, b_1, φ, U_3, a_3, b_3, Ψ are different.

The isolator design and the numerical simulation of the charge voltage in each Blumlein

The following principles for the isolator design should take account of:

(I) Since C_o and C_w are different, and C_o is smaller than C_w considerably, it can be expected that L_o will be larger than L_w greatly. Thus the coaxial two solenoidal coils configuration would be a suitable form for the magnetic flux coupling isolator construction. The wound directions of the two coils should be opposite from each other, and the coil ends are connected so that the fluxes from the two solenoid coils will be opposite when the Marx is charging the two Blumleins.

(II) The insulation between the isolator and its envirement, insulations between turns in each coil, insulation between the two coils, and surport construction insulations should all be able to hold off the maximum operation voltage. Ensuring the high voltage insulation strengths above to meet the riquirements, we should increase the values of L_o, L_w and M as high as possible so as to increase the isolation degree of the isolator and decrease the charge time delay.

(III) The other parameters of the accelerator are known, that is, $C_m = 21.7$nF, $L_m = 12.5\mu$h, $R_s = 2.98\Omega$, $C_w = 23$nf, $C_o = 2.99$nf. In order to determine the values of L_o, L_w and M, the numerical simulations should be made using Eq. (3), to see their influnces on the charge voltages and charge time delay of the two Blumeins, and choose their proper values to meet the requirements for the charge voltage distribution and charge time delays.

The values of the isolator parameters obtained from the simulation and insulation designs are as follows:

for coil L_w: its length $l_w = 40$cm, diameter $D_w = 28$cm, the total turns $N_w = 5$ turns, its winding wire is a copper strip with 55mm wide and 1.5mm thickness, and inductance $L_w = 4.8\mu$h.

for coil L_0: $l_0 = 40$cm, $D_0 = 16.5$cm, $N_0 = 50$ turns, its winding wire is a 3mm diameter copper wire, and $L_0 = 131\mu$h.

Each coil of the isolator is sealed with epoxy in vacuum and placed in a coaxial configuration with one end connected together and to the Marx output. The two coils were supported with two lucite rings at the connected end and in the middle of the two ends, respectively. The mutual inductance between the two coils $M = 13\mu$h.

Fig. 2 shows the changes of the $\overline{U_{BW}(t)}$ and $\overline{U_{BO}(t)}$ with L_o decreased from 131μh to 116μh and other parameters being constant. The curves I and II repressent $\overline{U_{BW}(t)}$ and $\overline{U_{BO}(t)}$ for $L_o = 131\mu$h, respectively; and the curves III and IV for $L_o = 116\mu$h. From this we can see that the maximum of the charge voltage in water line has some decrease but the increasing of the maximum of the charge voltage in oil line is obvious. That is, we can adjust the charge voltage distribution between the two Blumleins to meet the requirement by change the value of L_o.

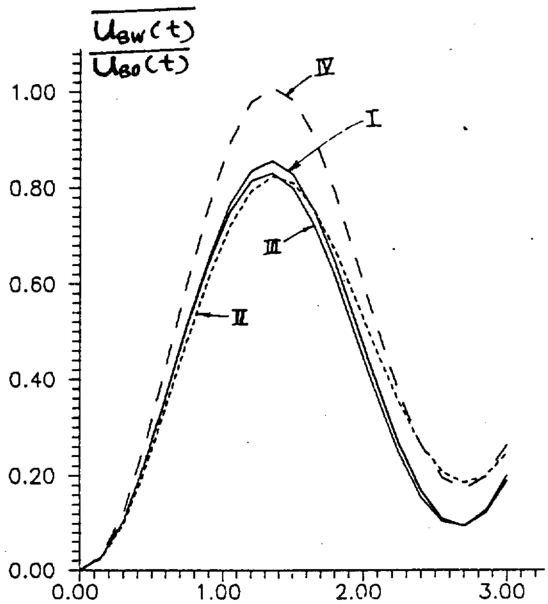

Fig. 2 – The change of $\overline{U_{BW}(t)}$ and $\overline{U_{BO}(t)}$ when L_o decreased from 136μh to 116μh.

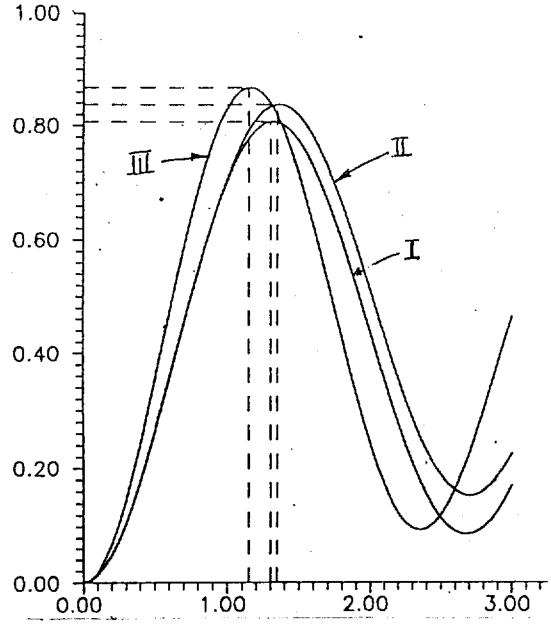

Fig. 3—The charge voltage wareforms in the two Blumleins. I $-\overline{U_{BW}(t)}$, II $-\overline{U_{BO}(t)}$; III $-\overline{U_B(t)}$.

The influnce of the leakage resistance R_w of water in Blumlein on the charge voltage $\overline{U_{BW}(t)}$ has not been taken account in Eq (3). Having taken the R_w into account, the charge voltage in water Blumlein can be expressed as:[2]

$$\overline{U_{BW}(t)} = U_0 \cdot e^{-a_0 t}[1 + U_1 e^{-a_1 t} \cdot \cos(b_1 t - \varphi) + U_3 e^{-a_3 t} \cdot \cos(b_3 t - \Psi)] \quad (4)$$

where, $a_0 = 1/R_w(C_m + c_w)$. When the resistivity of water $\rho_w = 3M\Omega-cm$, $R_w = 500\Omega$, and $a_0 = 4.48 \cdot 10^4 s^{-1}$.

Substituting all the parameter values into Eq (4), we can obtain the charge voltage waveforms $\overline{U_{BW}(t)}$ and $\overline{U_{BO}(t)}$ which are curves I and II, respectively, shown in Fig. 3. For the sake of comparison, the waveform of charge voltage $\overline{U_B(t)}$ for the single water Blumlein operation is also shown in Fig. 3, the curve III.

THE EXPERIMENT RESULTS

(1) The voltage transmission efficiencies of charging the two Blumleins and the times corresponding to the first maximums of $\overline{U_{BW}(t)}$ and $\overline{U_{BO}(t)}$, which are measured when 81–7M–01–A operating, are listed in table I.

Table I.

	η_m	η_D	t_m
water line	80.7%	72.6%	1.30μs
oil line	83.7%	75.4%	1.35μs

where, $\eta_m = U_{B,m}/U_m$ is the voltage transmission efficiency from the Marx to Blumlein. $U_{B,m}$ is the first maximum of $\overline{U_B(t)}$. The η_m will be $\eta_{mw} = U_{BW,m}/U_m$ and $\eta_{mo} = U_{BO,m}/$

U_m for the water Blumlein and oil Blumlein , respectively. $\eta_D = U_T/U_m$ is the tolal voltage trasmission efficiency from Marx to the output U_T of Blumlein. The tm is the time corresponding to the first maximum of $U_B(t)$, and the t_{mw} and t_{mo} are the times for $U_{BW}(t)$ and $U_{BO}(t)$ to reach their first maximums, respectively. We can see that the measured values of η_{mw}, η_{mo} t_{mw} and t_{mo} are in good agreement with the calculation results shown in Fig. 3.

(2) When 81－7M－01 IREBA with single Marx and single water Blumlein operating, the $\eta_m = 87\%$, $t_m = 1.18\mu s$. We can see that when one Marx operating two Blumleins, the decrease of voltage transmission efficiency in water Blumlein is about 6%, some of this energy has been transferred into oil Blumlein. The use of the isolator results in the increase of charge time in water line only about 0.12μs, leading to the decrease of η_m in water line less than 3%. From $E_{br} = K_{\pm} t_{eff}^{-1/3} A^{-1/10}$, we obtain $|\triangle E_{br}/E_{br}| \leqslant 5\%$, that is, the decrease of insulation strength is less than 5%, within the original safe margin.

(3) Fig. 4 shows the influnce of closing the oil Blumlein switch on the charge process in water Blumlein. The curves I and II are the $U_{BW}(t)$ and $U_{BO}(t)$, respectively, in the case that the switches on water Blumlein and oil Blumlein do not close. Curve I′ is the $U_{BW}(t)$ in the case that the switch on oil Blumlein had closed at a given time (curve II′), but the switch on water Blumlein unclosed. Fig. 5 shows the influnce of closing the water Blumlein switch (curve I′) on the charge process in oil Blumlein (curve II′). The curves I′ and II′ are the $U_{BW}(t)$ and $U_{BO}(t)$, respectively, in the case that the switch on water Blumlein had closed before the closing of switch on oil Blumlein. From this we can see that the influnce of closing the switch on one Blumlein to the charge process in another Blumlein is considerably smaller than that in single inductor isolation; no matter on which Blumlein the closing switch is. By the time one Blumlein switch has closed for 0.5μs, the charge voltage drop in another Blumlein is less than 10%. The operation voltage of water Blumlein or oil Blumlein can be adjusted individully in quite large ranges, do not affect the normal running in another blumlein. The performance in generating two electron beams is the same as generating one single elecfron beam individully by operating the one single corresponding Blumlein from the Marx.

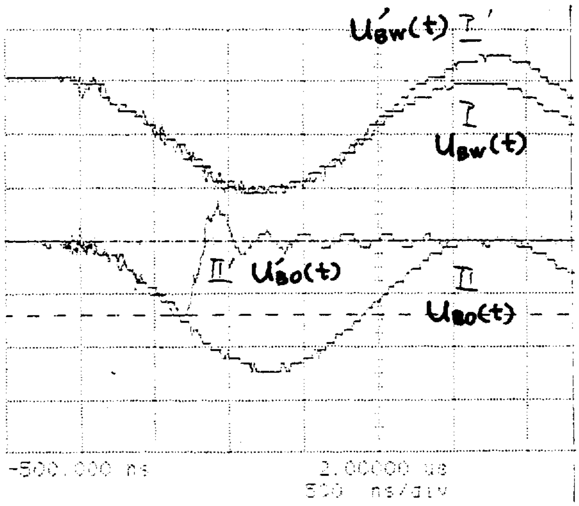

Fig. 4—The influnce of closing the oil Blumlein switch on the charge process in water Blumlein.

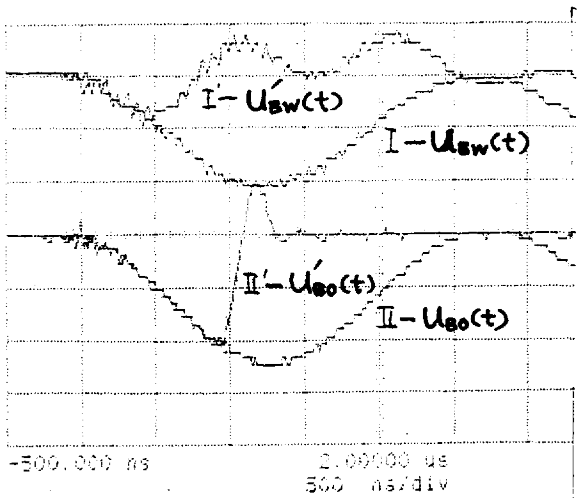

Fig. 5 － The influnce of closing the water Blumlein switch on the charge process in oil Blumlein.

CONCLUSION

81 - 7M - 01 - A Two - Beams Accelerator, operating one 6Ω water Blumlein line and another 40Ω oil Blumlein line from one Marx generator at the same time by the use of magnetic flux coupling isolation technique, may generate two electron beams which are in different ranges of beam currents. The isolation degree between the two Blumleis in operation is high, the performance for generating two elecfron beams is good, and it is easy to operate and to adjust individually. The functions of this accelerator are equal to that of the operation of two sets of IREBA with different impedances at the same time. The cost and room are saved. The analysis and design method presented in this paper had been demonstrated by the development of 81 - 7M - 01 - A Two - Beams IREBA, and will be true for the designs of such IREBA with the two defferent output impedances, using the single inductor isolation method or magnetic flux coupling isolation method.

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